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THE GENERAL MAGNETIC SURVEY OF THE EARTH*

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The famous mathematical physicist Stokes is said to have remarked that we must not forget that the chief instrument of investigation, the mind, is itself the object of research. Possibly no one means or instrumentality has contributed more powerfully to discoveries and research in the science represented by this joint gathering tonight—geography—than the magnetic compass. You have accorded me the privilege of showing briefly this evening how this instrument of investigation has itself been made the object of a research not only coextensive with the boundaries of the planet we inhabit but even transcending them. We shall find, as we pursue our studies of that mysterious force called the earth's magnetism, that we are, indeed, limited by no well-defined boundary as, for example, the earth's surface, but are carried far out into limitless space and even to the sun itself.

Professor J. A. Fleming closed his suggestive popular address before the British Association for the Advancement of Science, at Liverpool in 1896, on "The Earth, A Great Magnet," as follows:

> "To us as a maritime nation, to you who are inhabitants of a maritime city, the progress of a knowledge of terrestrial magnetism, the improvements in the compass, the study of the causes of error in iron ships, in short, everything connected with the use and evolution of the compass, is of unspeakable importance. * * *
>
> "That great empire which has its center in these islands, but its dominions

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* The evening lecture given before the first joint meeting of the American Geographical Society and the Association of American Geographers in New York, April 3, 1914; illustrated by lantern slides.

scattered over distant seas, has been built up primarily on the art of navigation, in which the magnetism of the earth is a central fact. Neither its worldwide commerce, nor the naval power which defends its coasts, could exist for a day without the aid of the magnetic compass. But our globe, as it spins through space, is clothed, as it were, in a gossamer garment woven of lines of magnetic force, and this little trembling needle serves as a sensitive finger, whereby we track out the path of these invisible clues, and, confidently determining our direction, though wandering over wide waters, wrapped, it may be, in darkness or in storm, are enabled thereby to establish a continual intercourse between all portions of the habitable globe.''

THE EARTH'S LINES OF MAGNETIC FORCE

Gilbert in 1600 had already spoken of the rays of magnetic force emanating in all directions from the lodestone's center, and thus forming an ''orb'' or ''sphere of influence'' around ''that great magnet, the earth.'' ''Like as the tender mother draws the suckling babe to her breast,'' runs a Chinese saying, ''so does the stone draw unto itself the all-conquering iron.'' No wonder then that the lodestone has also been called the lovestone; indeed the French still call the magnet ''l'aimant.'' And its mysterious sphere of influence—Gilbert's ''orbis virtutis,'' Fleming's ''gossamer garment, woven of lines of magnetic force,'' surrounding and extending far beyond the visual boundary of the lodestone, endowed the latter, from the earliest times, with many peculiar properties and gave rise to many queer superstitious notions.

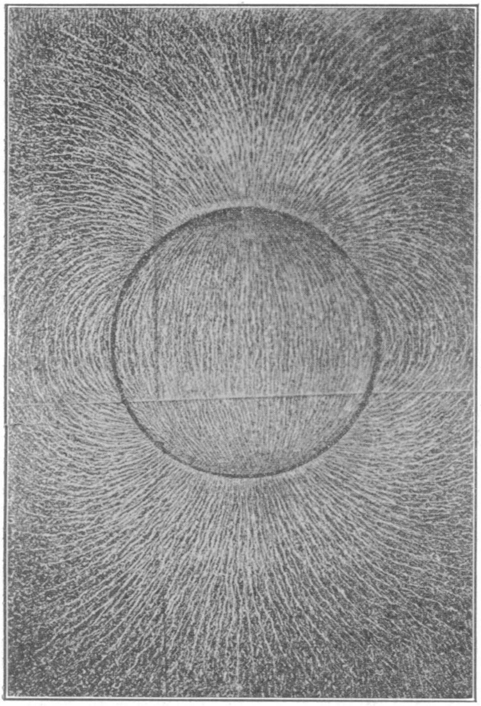

FIG. 1—Lines of force of a uniformly magnetized sphere. [The earth's magnetic field is not of this simple character; its magnetic poles are, on the average, 1,200 miles distant from its geographic poles and they are not diametrically opposite each other. A straight line connecting the earth's magnetic poles would pass through the earth 750 miles off from the center.]

The term "lines of magnetic force" for the paths traced out by the iron filings strewn around a magnetized body, we owe to Michael Faraday. The many brilliant and fruitful researches in magnetism and electricity by this indefatigable worker during the first half of the last century were in no small measure inspired by this happy conception of a "field" and "lines of force" about a magnet.

Picture then to yourselves these lines of magnetic force (Fig. 1) starting out from the earth's south magnetic pole and, after sweeping far out into space, curving gracefully around high above our equator and reentering finally at the north magnetic pole. Recall now that, while these lines cannot ordinarily be seen, they are made apparent to us by the beautiful phenomenon of polar lights, whose flickering flames and shooting rays arrange themselves in accordance with the earth's lines of magnetic force, and "dance in rhythm with the quivering needle." What is the origin of these lights? According to the latest theories, it is believed that when the tiny electrically-charged particles, continually being given off by our sun, come within reach of these lines of force, they are made to wrap themselves around them, descending into the polar regions along a spiral staircase, as it were. Before reaching the earth's surface, however, at heights of about twenty-five to three hundred miles, they are brought into luminescence, and thus we have the aurora borealis in the arctic regions and the aurora australis in the antarctic.

Who knows what part the earth's lines of magnetic force may not play, in the economy of nature, by carrying away and thus preventing an over-charge of electrified particles, shot off by the sun, from penetrating so low down towards the earth's surface as to be, perhaps, not wholly beneficial to man's physical well-being? Thus the earth's magnetic atmosphere, or aura, so to speak, may perform a screening function, with respect to these electrified particles, similar to that of the atmospheric envelope which comes within the ken of the meteorologist, in warding off the meteoric projectiles forever being hurled at us by our celestial neighbors.

We were then right when we surmised that our studies of the earth's magnetism, or what is the same thing, of the earth's surrounding magnetic field as traced out by its lines of magnetic force, carry us "far out into limitless space and even to the sun itself." And as we progress in our subject let us ever keep before us Professor Fleming's beautiful imagery: "The earth spinning through space, clothed as it were, in a gossamer garment, woven of lines of magnetic force." We shall find that the earth is not alone in this respect.

Our duty, at present, then, is to map completely, over the earth's immediate surface, its lines of magnetic force, though later we may attempt to do the same in ocean depths and atmospheric heights. We must ascertain, at each place of observation, whether the vertical plane passing through any given line of force coincides with a meridional plane of the earth and, if not, what the angle of divergence is; or, in other words, we must measure the angle which the direction pointed out by a compass needle makes with a true north and south line. This angle is reckoned as so many degrees east or west of north and is known to the mariner and surveyor as the "variation of the compass," and to the man of science, who finds need for more precise terms, as the magnetic declination. In the United States, for example, the magnetic declination varies at present from 22° West, in Maine, to 23° East, in Oregon.

But we also must know the steepness of the lines of force, that is, the angle at which they enter or emerge from the earth. This angle is measured with the aid of the well-known instrument, the dip-circle. The angle which the dipping needle makes with the horizon, if the vertical plane of the dip-circle passes through the magnetic meridian, *i.e.*, the direction defined by the compass-needle, is called the magnetic inclination or dip. At the north magnetic pole, the dip-needle stands vertical with the north end down, whereas at the south magnetic pole, the south end is down. Half way between, at the so-called magnetic equator, a dip-needle sets itself with neither end up or down but, instead, lies truly horizontal.

Knowing both the magnetic declination and the magnetic inclination, we are able to map out completely the direction everywhere assumed by the earth's lines of magnetic force. But this is not sufficient either for theory or for the practical application of the earth's magnetic phenomena to the everyday affairs of man. Thus, in order to correct properly a compass on a modern ironclad, or in other words, in order to counteract effectively on the compass the disturbing influence of the ship's own magnetism, due to the iron and steel entering into her construction, we must know, in all the oceans traversed, how strong or weak is the force exerted by our earth-magnet. Hence, our third and final element of observation is the so-called "intensity of the earth's magnetic field."

THE EARLIEST OBSERVATIONS AND THE EARTH'S CHANGING MAGNETISM

It was a discovery respecting the direction assumed by the compass-needle which gave definition to the first boundary line of

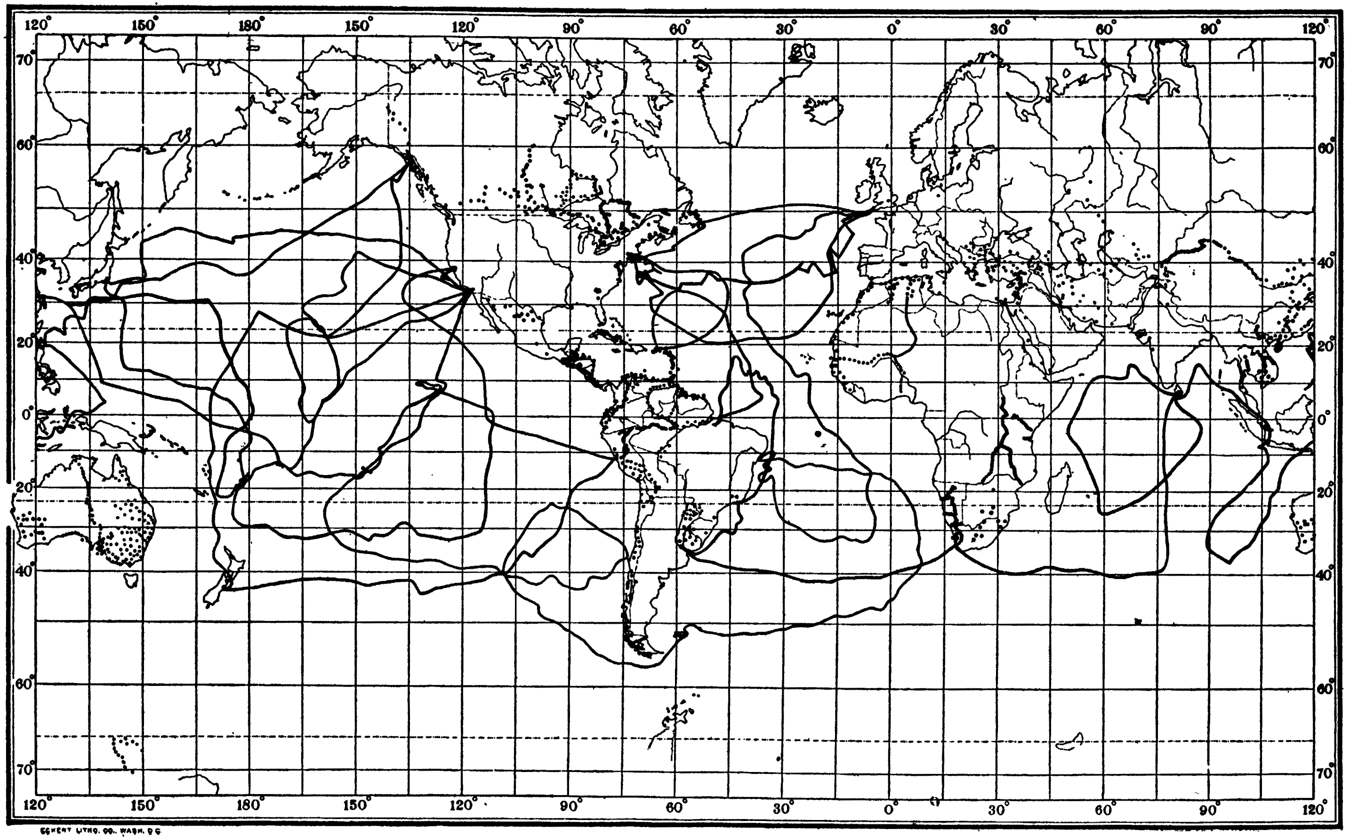

FIG. 2—Status of the field operations of the Department of Terrestrial Magnetism, 1905-1913.

great political importance. On September 13, 1492, during that memorable first voyage of Columbus, when they were off one of the islands of the Canaries, the compass, to the great consternation of the sailors, was found to point west of the polar star. From the time of embarking from the Spanish coast, the compass had been pointing east of that star, hence east of true north. To quiet the superstitious sailors, it is said that the doughty admiral shifted the compass card with respect to the needle so that the compass bore true again and he thus led them to believe that it was the star that varied its position and not the compass its direction. The fact is that during this voyage they crossed, in the meridian somewhat west of Fayal, one of the Azores, the agonic line, or line of no magnetic declination or variation of the compass, along which the magnetic needle sets itself exactly north and south (Fig. 3). At Palos, the port from which Columbus sailed, the magnetic declination was about half a point east and diminished to zero when the agonic line was crossed. Then the compass pointed to the west of north by an ever-increasing amount until in about mid-ocean the bearing was as much as a point. From that time, it diminished and when at last land was reached, the compass-bearing was about half a point west.

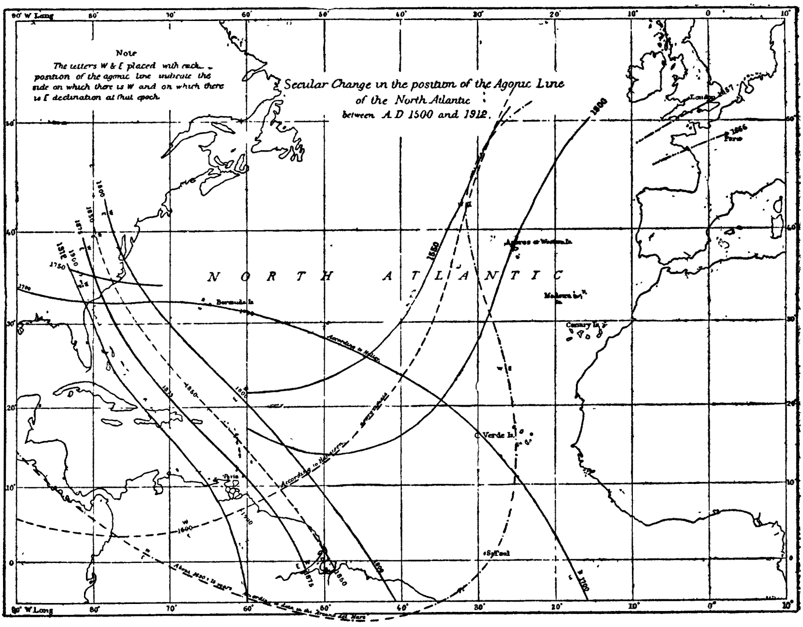
90° W Long
80°
70°
60°
50°
40°
30°
20°
10°
0
10°
50°
40°
30°
20°
10°
0
Note
The letters W & E placed with each position of the agonic line indicate the side on which there is W and on which there is E declination at that epoch.
Secular Change in the position of the Agonic Line of the North Atlantic between A.D 1500 and 1912.
N O R T H A T L A N T I C
Bermuda Is
Azores or Western Is.
Madeira Is.
Canary Is.
Verde Is.
1500
1550
1600
1650
1700
1750
1800
1850
1875
1900
1912
90° W Long

FIG. 3—Secular change in the position of the agonic line of the North Atlantic between A.D. 1500 and 1912. Chiefly after C. A. Schott and W. van Bemmelen.

This line along which the needle pointed exactly north and south, in the time of Columbus and Cabot, was believed to be a convenient line, "given by nature herself" from which to reckon longitude and it figured prominently in history for many years as the line of demarcation between the rival kingdoms of Portugal and Castile. Alas, however, for human invention, it was soon found that this line, far from being straight, is very devious, indeed, and, what is worse, it is not even fixed in position, having now disappeared almost entirely in the North Atlantic Ocean, though it may come back again in the distant future.

Just who first discovered that a compass, except at few places, does not point true north and south, can not be definitely ascertained. It would appear from some early sun-dials, that this fact may have been discovered before, or at least independently of, the voyage of Columbus. However, it can not be denied that it was his voyage which first definitely showed that the compass, contrary to the poet's line—"True as the needle to the pole,"—usually does not point to the true north but that the amount of divergence varies from locality to locality. The necessity in navigation for measuring the angle by which the north end of the compass points east or west of north, thus became definitely apparent in 1492, and hence this must be regarded as the year of the birth of the science of terrestrial magnetism, which has for its primary object the measurement of the earth's magnetic elements, *i.e.*, the making of so-called magnetic surveys.

Probably the first systematic magnetic survey, though it was but a partial one in that it concerned itself with only one element, the magnetic declination, was that under the leadership of the famous English astronomer, Edmund Halley, known to most of us as the discoverer of Halley's comet which reappeared a few years ago. Under orders from the British Government, between 1698 and 1700, Halley cruised up and down the Atlantic in command of the sailing ship, the *Paramour Pink,* and diligently observed the "variation of the compass" and "the true situation both of longitude and latitude of the ports" he visited. He laid down the result of his labors on a chart, sometimes briefly called the "Tabula Nautica," which was the first of its kind. Quoting Halley: "What is here properly *New* is the *Curve Lines* drawn over the several Seas, to show the degrees of the *Variation* of the *Magnetical Needle,* or *Sea-Compass.*"

Halley's chart and its successors soon won among mariners well-deserved popularity, but by about the middle of the eighteenth century, or fifty years after the first issue, in 1701, the "Curve Lines" were found to have changed so much as to require their complete reconstruction. For "the magnetic state of our globe is one of swift and ceaseless change and but a few years suffice to alter it materially."

This "swift and ceaseless" change in the earth's magnetic state was strikingly made evident when, in the fall of 1909, there set out from the shores of Newfoundland another sailing vessel, of which we shall have more to tell later. Beset by October gales she, nevertheless, unerringly followed, all the way to England, very nearly the identical track pursued by Halley's vessel 210 years before, and like Halley's vessel was also bent on measuring the "variation of the compass." Such great changes were found that, if the latter had attempted to follow the same magnetic courses as those of the *Paramour Pink,* instead of coming to anchor in the quaint, old harbor of Falmouth, her landfall would have been somewhere on the northwest coast of Scotland.

MAGNETIC SURVEY OF THE OCEANS

Though many noteworthy expeditions could be mentioned which, in the interim between Halley's and those of the Carnegie Institution of Washington, obtained credible magnetic data incidental to other work or objects, and while also naval vessels of various nations have contributed, from time to time, useful information, during all these two hundred years no vessel had been sent out by any country for the sole purpose of making magnetic observations. Thanks to the munificence of one, well-known to all of you, it became possible, on April 1, 1904, just ten years ago, for the Trustees of the Carnegie Institution of Washington to establish a department which could undertake as its chief task a systematic magnetic survey not only of the oceans, but of the whole earth, on a scale and with a dispatch not heretofore possible.

After some preliminary investigations, it became evident that the first ocean magnetic survey to be undertaken was that of the Pacific, for it was in this region that the Halleyan "Curve Lines" on which mariners depended, were known, because of the paucity of data, to be more or less uncertain. New instruments had to be in part devised, for our survey was to be far more comprehensive than Halley's could be and was to embrace all the necessary observations for completely defining the direction and intensity of the earth's magnetic force at sea. Time will not permit us to enter into details; suffice it to say that we were ready to embark on our first voyage in July, 1905, from San Francisco, in a chartered vessel, the *Galilee,* which we had been able to make approximately non-magnetic. During the three years (1905-1908) that the vessel was in commission, her cruises aggregated in length 60,000 miles and extended from Sitka, Alaska, in the north, to Port Lyttelton, New Zealand, in the south.

The *Galilee,* with the changes made, proved to be more non-magnetic than any modern vessel on which magnetic observations had been attempted. It was found that, with our appliances and methods, the results were of such accuracy as to warrant applying the corrections due to the remaining iron in the *Galilee* which, without reconstructing the vessel, could not readily be replaced by non-magnetic metal. These so-called deviation-corrections, though small, were yet, if they were not known, large enough to defeat our purpose to determine the amount of change in the magnetic elements by repeating the observations at the intersections of our tracks, three or five years apart., But to determine such corrections with the requisite accuracy proved to be a laborious process which cost as much, in time and money, as the acquirement of the primary or original quantities themselves. Hence arose the desire for a vessel on which magnetic observations could be made unaffected by any local influence due, for example, to the iron in her construction.

Accordingly, the *Galilee* was returned to her owners in May, 1908, and, with the funds provided by the Carnegie Institution of Washington, the project of building a vessel specially adapted to the varied purposes of ocean magnetic surveys, was undertaken. The designs were prepared by the well-known naval architect of New York, Mr. Henry J. Gielow, following suggestions based upon the experience gained by us during the work of the *Galilee.* The vessel was built by the Tebo Yacht Basin Company of Brooklyn, under the personal supervision of Mr. Wallace Downey. Nearly all materials entering into her construction were obtained in New York or within a distance of about fifteen miles.

Thus the non-magnetic *Carnegie* came into being. Launched in June, 1909, she entered on her maiden cruise of 8,000 miles in the following August. Since then this little vessel has made cruises in the Atlantic, Indian, and Pacific oceans, between the parallels of about 50° N. and 50° S., aggregating in distance four times the earth's circumference; and she will soon leave New York once more, this time for a cruise in the North Atlantic, towards the Norwegian coast and return. Next year, I hope, she will pass through the Panama Canal and enter upon a cruise in southern waters between the parallels of about 50° S. and 70° S., where no systematic magnetic work has been done since the memorable voyages of the *Erebus,* the *Terror* and the *Pagoda,* seventy years ago.

The *Carnegie* (Fig. 4) is 155½ feet in length over all, 128⅓ feet on the load-water line, 33 feet beam, draught 13½ feet, displacement about 600 tons, and is built almost entirely of wood fastened together with locust-tree nails, copper and Tobin bronze bolts, and composition spikes. Although she is practically a sailing vessel, brigantine-rigged, she has a small amount of auxiliary power, a producer-gas engine, which, with the exception of the pistons and cams, is wholly built of brass and copper. The small amount of steel, 600 out of 20,000 pounds of metal entering into the construction of the engine, is so far removed from the observing instruments as to have no effect. The anchors, of which there are four, aggregate weight 5,500 pounds, are bronze. The rigging is of hemp, the metal parts being all of bronze or copper. As we could not use iron chains for the anchors, and as a bronze chain of the required strength was too expensive, 11-inch hemp cables, each of 120 fathoms, were adopted; this made it necessary to use the old fisherman windlass.

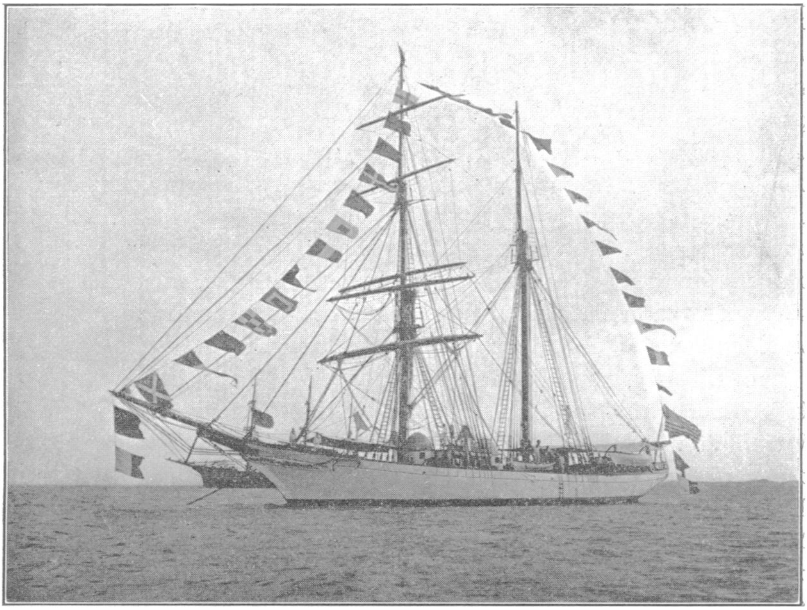

Fig. 4—The *Carnegie* at Bahia, Brazil, May, 1913. Dressed in honor of the port anniversary.

The three life-boats are non-magnetic, the galley stoves and refrigerating plant of bronze and copper, the sailors' sheath-knives of non-magnetic manganese steel, and our cutlery of Mexican silver. Do you wonder that facetious newspaper reporters have dubbed the *Carnegie* "the most unattractive vessel afloat"? Thomas Hood, in his amusing poem, "The Compass, with Variations," evidently anticipated the *Carnegie,* for he says:

> "They found no gun—no iron—none
> To vary its direction."

And he even remarks: "*Bronzed* mariners were her's to view!"

On the *Carnegie* the instruments are under shelter. The glass dome of the observatory can be revolved like the dome of an astronomical observatory, two of the glass panels being removable, so that both astronomical and magnetic observations may be made with complete protection from wind and weather. Having a vessel in which the deviation-corrections, if any, are on the order of or less than the error of observation, as has been proved by elaborate tests made at various ports, it is now possible to compute the observations on board and know the results within an hour after they are made. On arrival at port, the results are promptly transmitted to the office at Washington, whence they are supplied to the leading hydrographic establishments—to the British Admiralty, the German Seewarte, the U. S. Hydrographic Office, etc. The data of interest to mariners are also being promptly published in each issue of the quarterly journal *Terrestrial Magnetism and Atmospheric Electricity.* Thus the magnetic declinations observed on the *Carnegie* up to her return, last December, have already appeared in print.

The exclusion of possible disturbing effects on the instruments has been carried out quite rigidly. The construction of the observatories is such that it is not possible for a sailor, for example, to bring anything nearer to the mounts of the instruments than eight to ten feet, and the observers are required to state on the observation-forms whether they have removed from their persons all iron or steel articles. The entire personnel is composed of twenty-one men, five usually in the scientific party, and sixteen in the crew, including the watch officers.

This interesting vessel travels at an average rate of about 150 miles a day, from port to port, crisscrossing back and forth in all the oceans. While she carries nearly 13,000 square feet of plain sail, sufficient, with a fair wind, to cover 300 miles a day, and while she has at times, in fact, approximated this speed, no attempt is made to go beyond 150 or 200 miles, as this is the desired average distance apart for our magnetic observations at sea.

Daily, even under conditions of sea and weather that before the introduction of our appliances and methods appeared prohibitive of the requisite accuracy, are the zealous observers busy with measuring and promptly computing the magnetic elements. And they likewise make the necessary astronomical observations for the navigation of the ship and the determination of the latitude and longitude of the place of observation. They, furthermore, engage in other useful work, such as meteorological observations, determining the electrical elements of the atmosphere, the amount of atmospheric refraction, etc., so that they are busy from early morn until evening twilight. The evening is devoted to amusement. In this way a passage of six weeks or more between ports passes before one is aware.

The *Carnegie,* while working wholly under private auspices, is recognized universally as carrying out a mission not for the good of any one nation but of all nations. In consequence, the privileges extended to visiting men-of-war are accorded to her and she is the object of courteous attention at every port. Her book of visitors contains the names of many noted personages, among whom was Mark Twain at Bermuda, shortly before his death.

A chart (Fig. 2) shows the cruises thus far accomplished by the *Galilee* (1905-08) and the *Carnegie* (1909-13). The latter has now successfully completed, under the command of W. J. Peters, two cruises: the first of 8,000 miles in the North Atlantic between August, 1909, to February, 1910, in which the ports of call were, St. John's (Newfoundland), Falmouth (England), Funchal (Maderia), and Hamilton (Bermuda); the second, a world-encircling cruise of over 92,600 miles, in the Atlantic, Indian, and Pacific Oceans, starting at Brooklyn in June, 1910, and including the ports San Juan (Porto Rico), Para (at the mouth of the Amazon), Rio de Janeiro, Buenos Aires, Capetown, Colombo (Ceylon), Batavia, Manila, Suva (Fiji), Tahiti, Coronel (Chile), Stanley Harbor (Falkland Islands), St. Helena, Bahia (Brazil), St. Helena (second time), Falmouth (England), and ending at Brooklyn last December. The total mileage of the two vessels up to date is about 160,600.

You will observe that the tracks interlace and frequently cross, this being done intentionally in order to supply, by repeating observations at the points of intersection, both desired control and the necessary data for determining the amount of change in the magnetic elements since an earlier cruise. For similar reasons, our cruises have been arranged so as to intersect the routes of other vessels on which a certain amount of magnetic work had previously been done.

The three magnetic elements, declination, dip and intensity, have been determined along the various tracks at points averaging 150 to 200 miles apart. With our special appliances and with the methods of observing employed, it has been possible to achieve an accuracy in magnetic observations on a moving vessel not hitherto attained. In fact, under fair conditions of sea and weather, and devoting the same amount of time for the ocean work that it is customary to spend in land work, we have demonstrated that the absolute accuracy of the ocean work approaches closely that of the land work in which fixed mounts for the instruments can be had.

The errors in the magnetic declination-charts reached 6° in the Indian Ocean. The errors in the dip-charts amounted frequently to 5° or 6°, and in the horizontal intensity to about 5 per cent. of the value. Often the errors are of the same sign for long stretches; and from the values found at the points of intersection of our tracks, it has been shown that the chart errors are caused, to a large extent, by erroneous secular changes assumed in referring past observations to a later date.

But we must not forget that, although the oceans cover about seven-tenths of the surface of our globe, it is equally important to science, as well as to the geographer and surveyor, to trace the folds of our ''gossamer garment, woven of lines of magnetic force'' over the land areas as well. This is a matter of no little interest also to the geologist, for many interesting correlations are found between irregularities in the distribution of the earth's magnetism over the land and geologic formations.

Except when approaching land, or in shallow water, the isomagnetic lines over the oceans appear to run smoother than over land. Largely on this account, now that we have a vessel specially suited and have our appliances perfected by an experience of nine years, it is found easier and more expeditious as well, to make an ocean magnetic survey than a land magnetic survey. In the latter case more observations must be made, *i. e.,* at shorter distances apart, in order to eliminate, as far as possible, the purely local effects due perhaps to iron-bearing rocks nearby which affect the magnetic needle. Then again, the transportation over more or less untraveled countries presents problems not, in general, inherent in the ocean work. However, before passing to the land expeditions, let us turn aside a moment and consider another phase of magnetic work.

THE SUN, A GREAT MAGNET

While on an inspection trip during 1911, to join the *Carnegie* at Colombo, Ceylon, and to visit, en route, various land parties and magnetic observatories, advantage was taken of an enforced three-weeks' stay at Suva, Fiji, to observe the total solar eclipse on April 28, 1911. After various vicissitudes, too long to narrate, with the courteous aid of Acting Governor Schultz (now Governor) of German Samoa, and of Commander Crose (then Governor of American Samoa), I finally reached, on April 26, two days before the day of the eclipse, Manua Island, one of the Samoan group belonging to our country (Fig. 5). This island, being off from the regular line of travel, is rarely visited by the tourist. I, with my effects, was transported there from Pago Pago (Tutuila) on the United States gunboat, *Annapolis,* kindly put at my disposal by Governor Crose, who also gave me the desired scientific assistance by assigning to the proposed work various naval officers, to all of whom I am no little indebted for whatever success was achieved.

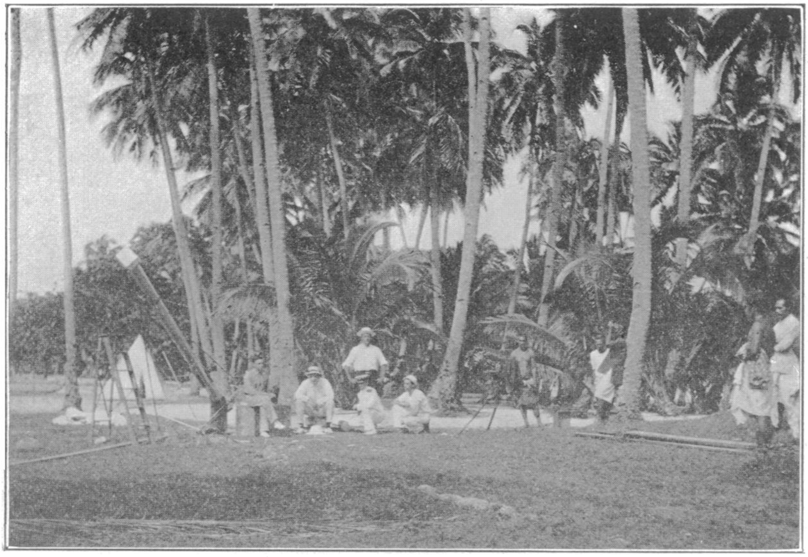

FIG. 5—L. A. Bauer's eclipse party and station on Manua Island, Samoa, April 28, 1911.

Fortunately, through the skill of an experienced pilot furnished by Governor Crose, all instrumental effects were safely landed through the breakers. Not enough can be said of the hospitality shown and assistance rendered by the Samoan inhabitants of the island. Queen Vaitupu quartered the observing party in her own house and the Samoan chiefs provided for our entertainment.

Though the day before the eclipse was cloudy and showery, the following day was clear and sunny. We alone of all the eclipse parties, as it afterwards turned out, were thus favored.[1]

Repeated observation has now clearly demonstrated that the soft, pearly light seen surrounding the sun when the moon blots out for the moment the sun's burning glare, known as the solar corona, passes through a cycle of changes in entire rhythm with the sun's activity as displayed by sunspots and solar eruptions. Furthermore, it has been repeatedly observed by various investigators, that the coronal streamers appear to curve towards the sun's poles as do the lines of force of a magnetized sphere. Hence, the inference is close at hand that, if the sun, like the earth, were a magnet, then perhaps the solar corona is a phenomenon similar to our polar lights. Within a year, it has been definitely proven by Professor Hale, Director of the Mount Wilson Solar Observatory of the Carnegie Institution of Washington, that the sun is indeed surrounded by a magnetic field with lines of force very similar to those enveloping our own planet.

Thus the earth is not alone clothed in "a gossamer garment, woven of lines of magnetic force." If the sun, in spite of its intense heat, at which no magnetism, as exhibited by our permanent magnets, could exist, nevertheless possesses a magnetic field, what is the agency essential for the production of a magnetic field? The query has been raised "whether every large rotating mass may not be a magnet." If the answer be affirmative, picture to yourselves orbs innumerable spinning through space surrounded by pulsating, vibrating fields of force, ever interacting and responding to each other's external influences. Daily are registered at our magnetic observatories messages from without which perhaps some day we may be able to interpret.

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[1] There was shown, on the screen, a reproduction, from a sketch, of this eclipse as seen at sea by Captain Holford of the steamer *Tofua*, and, alongside, a sketch drawn by the late Professor Langley of the eclipse of 1878. The juxtaposition of the two sketches exhibited a remarkable similarity between the two. The interval between the two eclipses was thirty-three years, or three times the sun-spot cycle. The years 1878 and 1911 were years of minimum sunspot activity.

LAND EXPEDITIONS

The dots, about 2,500 in number (Fig. 2) show where the observers of the Department have determined the magnetic elements on land. It will be seen that the land observations cover nearly all regions of the globe. The aim is to include in our survey only those countries where no organization exists prepared to undertake such work. The surveys in progress under other auspices are not shown on this map. It is gratifying to say that these surveys are being conducted in cooperation with our design of a general magnetic survey of the globe. The magnetic standards used by the various foreign organizations are compared from time to time with the standards of the Carnegie Institution, thus making possible a strict correlation of all magnetic data obtained the world over.

As an indication of the general interest evinced, the following resolution may be cited, which was passed at the St. Petersburg meeting of the International Association of Academies held in May, 1913:

> "The Committee, in view of the work of making a magnetic survey of the globe, particularly on the oceans, undertaken by the Carnegie Institution of Washington, resolves that it is of the highest importance that similar work be completed as soon as possible, in those countries where no surveys exist or where they have been made at epochs relatively distant from those of the Carnegie Institution of Washington."

It is not possible to individualize here the remarkable work accomplished by our observers. Suffice it to say that many of the expeditions, frequently embracing comparatively unexplored regions, have been attended with more or less danger, and have presented special difficulties which had to be surmounted. They represent geographic achievements as well as scientific work successfully accomplished under trying conditions, *e. g.*, the crossing of the Sahara from Algiers to Timbuktu and thence to Lagos, Nigeria; the complete crossing of China from east to west, of Australia from south to north, of South America from east to west and north to south; extensive canoe expeditions in British North America, etc.

SUMMARY

In a summary or general statement of what has been accomplished from 1905 to January 1, 1914, in execution of the design of the general magnetic survey of the globe, now about two-thirds completed, we may recite the following facts:

Mileage covered on the cruises of the *Galilee* (1905-08) and the *Carnegie* (1909-13), the magnetic elements having been determined completely, on an average, about every 175 miles.		160,600
Mileage covered by land expeditions in the establishment of about 2,500 stations in all parts of the earth, at an average distance apart of 75 miles, roughly		800,000
Total mileage traveled by ocean and land expeditions, in round numbers (or forty times the circumference of the earth)		1,000,000
Number of land expeditions sent out	38	
Number of Arctic expeditions cooperated with	4	
Number of countries in which magnetic work was done:		
Africa	25	
Asia	9	
Australasia	7	
Europe	5	
North America	13	
South America	12	
Island Groups, Atlantic Ocean	8	
Island Groups, Pacific Ocean	12	
Island Groups, Indian Ocean	3	
Total	94	
Number of articles and publications by members of the Department, about		125

Construction Work:

A non-magnetic vessel built (the first of its kind).

A building, containing forty-four rooms, erected to provide the necessary facilities for the research work at Washington (Fig. 6).

Seven new instruments devised and constructed, especially designed for ocean and land magnetic work.

While the figures given show that, thanks to the means provided by the Trustees of the Carnegie Institution of Washington, and the zeal of the observers, a large amount of work has been accomplished not of interest alone to the investigator of the earth's magnetism but to the geographer as well, the record we are proudest of is the fact that the entire work has been done thus far without loss of life. The *Carnegie* returned to Brooklyn last December after a successful cruise of 3½ years, during which she covered 92,600 miles in the Atlantic, Indian, and Pacific Oceans, without loss of sail, or spar, or human life. Surely a proud record for the Commander. And as to the land observers, if you will allow me to quote from a recent report:

> "It is impossible to refer to the observers individually in calling attention to the devotion, zeal, enthusiasm, and ability displayed in the successful accomplishment of duties well performed, at times under most adverse circum-

stances, in strange countries, amid strange people with strange customs and speaking a strange language; often over infrequently traversed roads and even at times in regions either rarely or never before, as far as known, reached by white man; pursuing the work faithfully, even when revolution was rife in the countries visited and travel was attended with many dangers; following steadfastly in the direction of their goal at no little sacrifice of personal comfort and even sometimes at the risk of life and limb. They have carried on their work in nearly all the regions of the globe from latitude 78° North (Greenland) to 43½° South (New Zealand)".

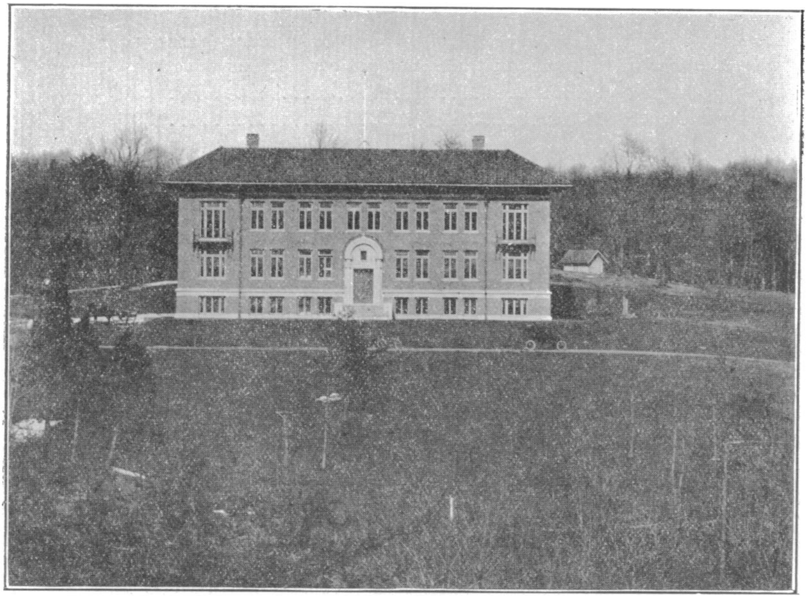

FIG. 6—Newly erected Research Building for the Department of Terrestrial Magnetism at Washington, D. C.

CONCLUDING REMARKS: THE CAUSE OF THE EARTH'S MAGNETISM

Possibly by this time, if not before, you may have said to yourselves: "Granted that the compass needle points north and south because the earth itself is a magnet, what, in turn, causes the earth's magnetism, why are the magnetic poles not only not situated at the geographical poles, but not even diametrically opposite one another, or why, instead of wandering to and fro with the lapse of time, do not the magnetic poles remain fixed in position?" Lest any of these questions should cause you sleepless nights, let me say that, for the present at least, it would appear the better policy to confess ignorance. We may also take comfort in the fact that if the student of the earth's magnetism has not yet discovered the true cause of his science, neither has the investigator of magnetism, in general, been able as yet to answer the question: "what is a magnet?"

The most famous astronomer of his time, Simon Newcomb, one day entered the office of the associate editor of the *Standard Dictionary*, expressing his dissatisfaction with the tentative definitions for the words "magnet" and "magnetism," as based, in the absence of authoritative knowledge of the causes, simply upon the properties manifested. He was promptly requested to try his own hand. After writing and erasing alternately for an hour or more, he finally, with a hearty laugh, submitted the following pair of definitions: "MAGNET, a body capable of exerting magnetic force." "MAGNETIC FORCE, the force exerted by a magnet." Equivalent definitions will be found in Ambrose Bierce's "Devil's Dictionary" and, in explanation, the author cynically remarks that they were "condensed from the works of 1,000 eminent scientists, who have illuminated the subject with a great white light, to the inexpressible advancement of human knowledge."

But after all, it would seem that it is not so much the Why and Wherefore as the Therefore by which human progress is most advanced. Man, as the astronomer Littrow jokingly remarked, is "das Ursachen-thier," who is ever incited and stimulated by his inquisitiveness as to the *cause* of things. Though he may never determine the "Endursachen," or ultimate causes, his inquiries lead him to acquire a vast amount of data with the aid of which he at least finds out the laws governing the phenomena under investigation.

The accumulation of data must at present be the chief aim of the student of the earth's magnetism. Perhaps no other subject can furnish more instances that, while theories as to the why and wherefore, though propounded by the most enlightened of the age, are short-lived, the facts accumulated by observation and experience remain as permanent acquisitions to the storehouse of human knowledge. In the words of Robert Louis Stevenson, whose island home we visited:

> "To travel hopefully is better than to arrive,
> And the true success is labor."